

# The relationship between primary production and the export of POM from the photic zone in the Mississippi River Plume and inner Gulf of Mexico shelf regions

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## Abstract

As part of the NOAA Nutrient Enhanced Coastal Ocean Productivity program we examined the relationship between rates of primary production and the vertical export of POM out of the photic zone in the Mississippi River plume and inner Gulf of Mexico shelf regions. The study was conducted during both high (March 1991) and low (July/August 1990) river discharge periods. July/August rates of production were 4-10  $\text{gCm}^{-2}\text{d}^{-1}$  in the plume and 2-4  $\text{gCm}^{-2}\text{d}^{-1}$  on the shelf. During March, production rates were 0.4-0.7  $\text{gCm}^{-2}\text{d}^{-1}$  and 0.1-0.5  $\text{gCm}^{-2}\text{d}^{-1}$  for the plume and shelf regions, respectively. During July/August, 3-9 percent of the POC production was exported out of the photic zone in both regions, while during March, 64-266 percent was exported. We attribute the observed export differences to temporal variability in phytoplankton species composition and in the activities of zooplankton grazers.

The Mississippi River drains more than 40 percent of the continental United States. In the past 35-40 years there has been a two-fold increase in the observed concentrations of  $\text{NO}_3^-$  measured in river waters near the modern "birdsfoot" delta (Turner and Rabalais, 1991; Dinnel and Bratkovich, submitted). Examination of monthly records have led Dinnel and Bratkovich (submitted) to conclude that seasonal variation in dissolved N concentrations, which are superimposed on a generally increasing trend, are linked with seasonal trends in river discharge. Higher nutrient concentrations are associated with higher river discharge rates (e.g. in winter and spring). Conversely, low river discharge appears to be correlated with lower nutrient concentrations in the river waters. It has been suggested that the observed increasing trend in dissolved inorganic nutrient concentrations could result in increased levels of primary production in the coastal regions of the Gulf of Mexico (Sklar and Turner, 1981; Lohrenz *et al.*, 1990). Further, it has been suggested that the increased levels of primary production would give rise to increased sedimentation of particulate organic matter (POM) and possibly contribute to the frequently observed episodes of hypoxia on the inner Gulf shelf (Turner *et al.*, 1987). One of the objectives of our study has been to examine temporal variability in primary production relative to variations in river flow for two

regions: the Mississippi River plume and the inner Gulf of Mexico shelf (cf. Lohrenz *et al.*, 1992). It is the goal of this study to examine the temporal variability in the relationship between primary production and the export of POM from the euphotic zone in the study regions.

## Materials and Methods

Two research cruises were conducted in the study regions onboard the NOAA ship MALCOLM BALDRIGE, one during a low river flow season (July/August 1990; Fig. 1a) and another during a high river flow season (March 1991; Fig. 1b). During each cruise studies were conducted in the Mississippi River plume and the inner Gulf shelf to measure primary production using simulated *in situ* incubations conducted in temperature, light quality and light quantity controlled deck-top incubators (Lohrenz *et al.*, 1991). Also, during each cruise free-floating MULTITRAP sediment trap arrays (Knauer *et al.*, 1979) were deployed, generally for one to two days, in both study regions to quantify the export of POM from the euphotic zone. Productivity experiments were coordinated with the sediment trap deployments; production experiments were generally conducted at sunrise of both days 1 and 2 of each trap deployment.

Water samples were collected prior to sunrise using either acid washed 10 L Niskin bottles or 30 L Go-Flo bottles from three depths corresponding to the 50 percent, 12 percent and 1.4 percent light depths. Samples were placed in 1 L polycarbonate bottles, inoculated with  $\text{H}^{14}\text{CO}_3^-$  and incubated from sunrise to sunrise. Trace metal clean procedures, as recommended by Fitzwater *et al.* (1982), were employed throughout the study. Zero time blanks were used to correct particulate  $^{14}\text{C}$  activities (Morris *et al.*, 1971). After the

## Acknowledgements

This research was supported by NOAA/Mississippi-Alabama Sea Grant No. NA90AA-D-SG688, Project No. R/LR-25. We also wish to acknowledge the technical help of D. D. Taylor and the cooperation of the Captains and crew of the N/S MALCOLM BALDRIGE on each of the research cruises. USM/CMS Contribution No. 0121.

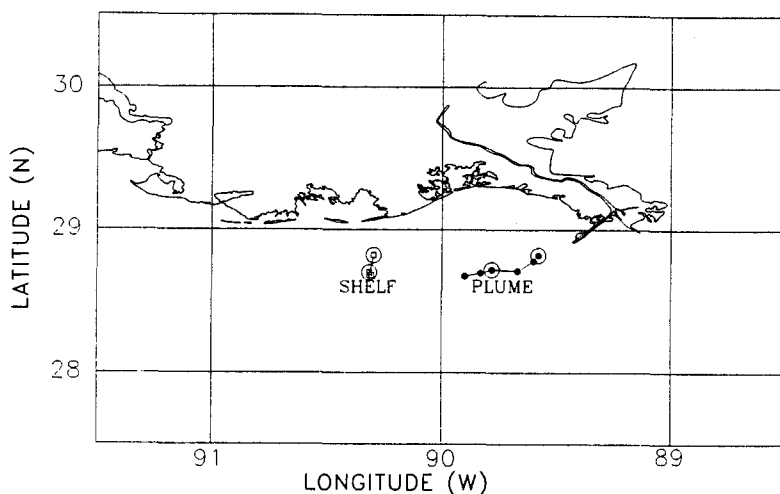
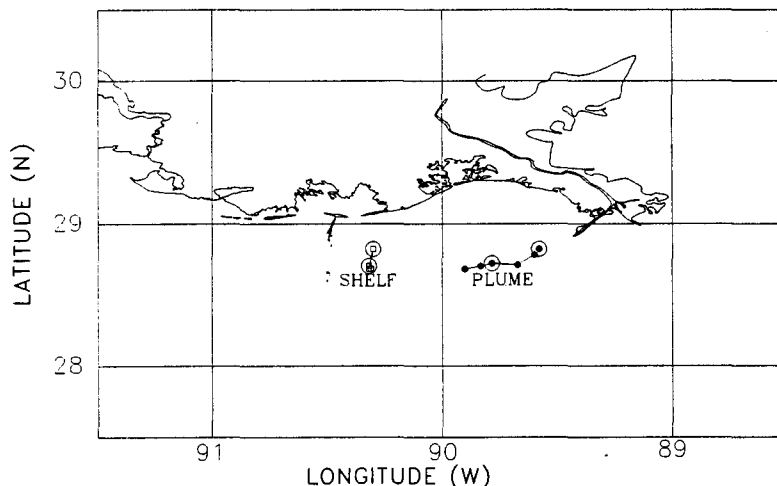


Figure 1a. Drift track of the free-floating sediment trap arrays deployed during the July/August 1990 cruise in the Mississippi River plume (filled circles) and the inner Gulf of Mexico shelf (open squares). The circled stations indicate the locations where primary production experiments were conducted.

Figure 1b. Drift track of the free-floating sediment trap arrays deployed during the March 1991 cruise in the Mississippi River plume (filled circles) and the inner Gulf of Mexico shelf (open squares). Primary production experiments were conducted at the stations located at the beginning and end of the drift tracks.



incubations were complete, replicate subsamples were filtered onto Whatman GF/F filters to determine particulate  $^{14}\text{C}$  activity. In most instances, post-incubation size-fractionation techniques (using Poretics 8  $\mu\text{m}$  filters) were employed on replicate productivity bottles to determine the production for that portion of the phytoplankton community which was  $<8\mu\text{m}$  in diameter. Subsamples were also taken to determine the total amount of  $\text{H}^{14}\text{CO}_3^-$  added to each bottle by combining 500  $\mu\text{L}$  of sample with 500  $\mu\text{L}$  of a 50 percent (v/v) mixture of ethanol and ethanolamine. Particulate  $^{14}\text{C}$  activity filters were treated as suggested by Lean and Burnison (1979) to remove residual  $\text{H}^{14}\text{CO}_3^-$ . Sample  $^{14}\text{C}$  activities were determined using SafetySolve liquid scintillation cocktail with a Packard Liquid Scintillation Analyzer.

Replicate (3-8) MULTITRAP sediment traps were attached to trap holder crosses and deployed at 15 m on free-floating arrays for each study region on both cruises (Fig. 1 a and b). Deployments were one to two days in duration. Prior to deployment, each sediment trap was filled with a brine solution (final density =  $1.08\text{ g kg}^{-1}$ , to prevent loss of collected materials upon recovery) containing 2 percent (v/v) formalin as a preservative. After recovery, trap contents were exam-

ined microscopically to remove any "swimmer" zooplankton which would contaminate the collected POM (Karl and Knauer, 1989; Knauer *et al.*, 1984; Lee *et al.*, 1988). The concentration of particulate organic carbon (POC) and particulate organic nitrogen (PON) collected in each trap were determined using a Carlo Erba NA1500 Nitrogen-Carbon Analyzer.

## Results

The results of the productivity studies are shown in Fig. 2 for the July/August 1990 cruise and Fig. 3 for the March 1991 cruise. In general, integrated primary production (IPP) rates were an order of magnitude greater in July/August 1990 than during March 1991. The  $<8\mu\text{m}$  components of the phytoplankton community were responsible for 65 percent of the total IPP in the Mississippi River Plume and 60 percent in the shelf region during July/August 1990. During March 1991, the  $<8\mu\text{m}$  size fraction was responsible for 68 percent of the total IPP in the plume region. The patchy nature of the study region is demonstrated by the results of production experiments for the shelf region during March 1991 (Fig. 3). IPP varied by more than a factor of 3 from day one to day two.

Tables 1 and 2 show the results of the sediment trap

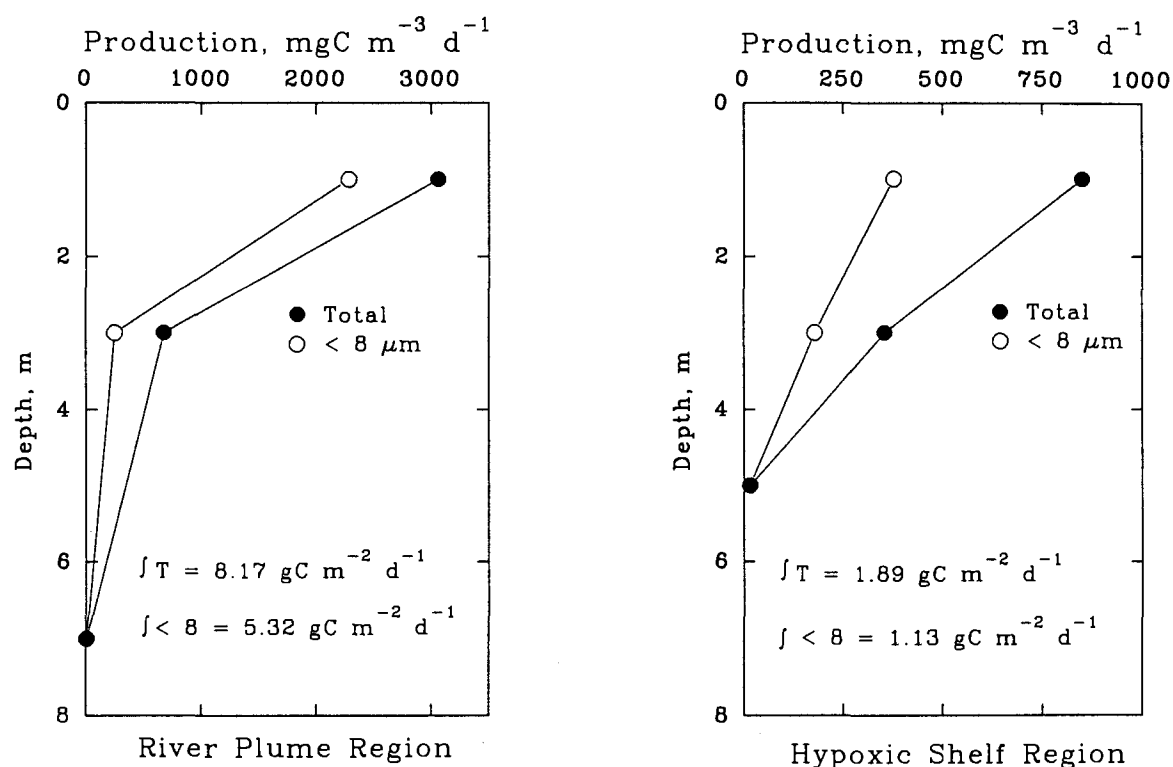


Figure 2. Simulated *in situ* primary production experiments conducted during the July/August 1990 research cruises in the Mississippi River plume and the inner Gulf of Mexico shelf. Post incubation size fractionation studies were conducted to determine the production of the  $< 8 \mu\text{m}$  components of the phytoplankton community. Values for production integrated from the surface to the base of the photic zone are indicated.

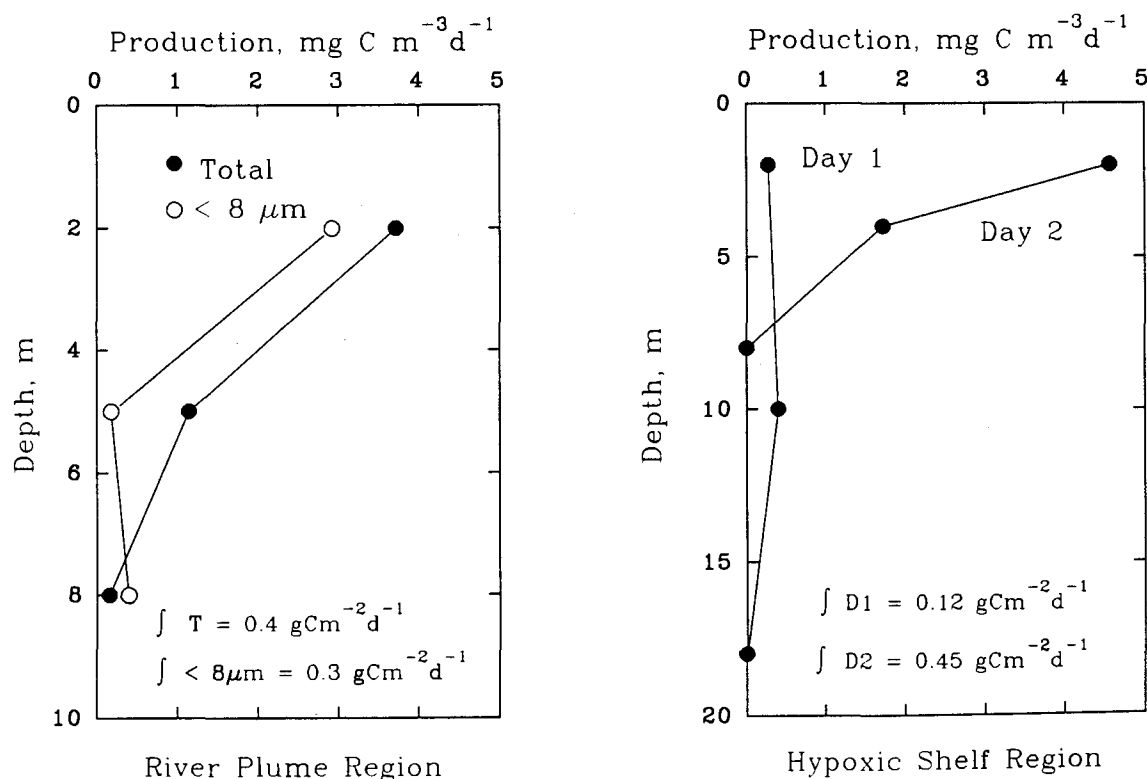


Figure 3. Simulated *in situ* primary production experiments conducted during the March 1991 research cruises in the Mississippi River plume and the inner Gulf of Mexico shelf. Post incubation size fractionation studies were conducted to determine the production of the  $< 8 \mu\text{m}$  components of the phytoplankton community in the Mississippi River plume only. Values for production integrated from the surface to the base of the photic zone are indicated.

**Table 1.** Integrated primary production (IPP) and the vertical export of POC and PON from the photic zone collected at 15 m in free floating sediment traps for both the Mississippi River plume (plume region) and the inner Gulf of Mexico shelf (hypoxic shelf region) from the July/August 1990 research cruise.

	Plume Region	Hypoxic Shelf Region
Integrated Primary Production (IPP)	4-10 gCm <sup>-2</sup> d <sup>-1</sup>	2-4 gCm <sup>-2</sup> d <sup>-1</sup>
Vertical Export of POC and PON POC (Standard Error, n)	0.29 gCm <sup>-2</sup> d <sup>-1</sup> (0.02, 3)	0.18 gCm <sup>-2</sup> d <sup>-1</sup> (0.007, 4)
Percent of IPP	2.9-7.3 %	4.5-9.0 %
PON (Standard Error, n)	0.06 gNm <sup>-2</sup> d <sup>-1</sup> (0.002, 7)	0.03 gNm <sup>-2</sup> d <sup>-1</sup> (0.002, 8)

**Table 2.** Integrated primary production (IPP) and the vertical export of POC and PON from the photic zone collected at 15 m in free floating sediment traps for both the Mississippi River plume (plume region) and the inner Gulf of Mexico shelf (hypoxic shelf region) from the March 1991 research cruise.

	Plume Region	Hypoxic Shelf Region
Integrated Primary Production (IPP)	0.4-0.7 gCm <sup>-2</sup> d <sup>-1</sup>	0.1-0.5 gCm <sup>-2</sup> d <sup>-1</sup>
Vertical Export of POC and PON POC (Standard Error, n)	0.95 gCm <sup>-2</sup> d <sup>-1</sup> (0.01, 3)	0.32 gCm <sup>-2</sup> d <sup>-1</sup> (0.02, 3)
% of IPP	136-237 %	64-266 %
PON (Standard Error, n)	0.16 gNm <sup>-2</sup> d <sup>-1</sup> (0.01, 6)	0.05 gNm <sup>-2</sup> d <sup>-1</sup> (0.002, 6)

experiments in the two study regions for the July/August 1990 and the March 1991 cruises, respectively. The vertical flux rates of both POC and PON out of the photic zone were two- to three-fold greater during the March 1991 cruise than for the July/August 1990 cruise. During July/August 1990, a relatively small portion of the IPP (2.9 - 9.0 percent) was collected in the sediment traps, while a much larger portion (64 - 266 percent) of the IPP was collected in the traps in March 1991.

### Discussion

It appears that the rates of primary production, the vertical export of POM from the photic zone and the relationship between the production and export of POM vary with time in both study regions. It is generally expected that high river discharge rates and seasonally high nutrient concentrations would occur during late winter and early spring, when incident irradi-

ance is low, leading to lower rates of IPP. During summer, when expected river discharge and the input of dissolved N are both relatively low and incident irradiance is higher, rates of IPP should be high. Conventional wisdom suggests that higher levels of IPP are associated with higher rates of vertical export of POM from the photic zone (Eppley and Peterson, 1979; Walsh *et al.*, 1989). It appears that our July/August 1990 cruise may have been at variance with long term average conditions (cf. Dinnel and Bratkovich, submitted) in that our cruise was preceded by a period of higher than normal river discharge and concentrations of NO<sub>3</sub><sup>-</sup> >20 μM in the river plume. These environmental conditions were not generally very different from those encountered during the March 1991 cruise. Thus, the differences in our observed rates of IPP and export of POM are likely not due to variability in the nutrient fields. Temporal variation in the irradiance field com-

bined with the absorption and scattering properties of the dissolved and suspended materials in the plume and shelf areas may contribute to the observed variation in primary production (Lohrenz *et al.*, 1990; 1992). However the differences in the ratio of the vertical POC flux to IPP cannot be explained solely on the basis of differences in IPP which result from heterogeneity in the physical and chemical environment. It appears that at least two additional factors contribute to temporal differences in the fraction of the organic matter produced in the photic zone that is exported to the sediments: differences in phytoplankton communities present and differences in the activities of both microzooplankton and macrozooplankton grazers.

Our data indicate that the  $>8\ \mu\text{m}$  components of the phytoplankton community, mostly composed of diatoms, were of lesser importance than smaller organisms in terms of their contribution to IPP during both the July/August 1990 (Dortch *et al.*, 1992; Fahnenstiel *et al.*, 1992) and March 1991 (Dortch *et al.*, 1992) cruises for the river plume and shelf regions. However, more diatoms, principally *Skeletonema costatum*, were found in the sediment traps deployed in the plume than in those deployed in the shelf region during the July/August 1990 cruise (Dortch *et al.*, 1992; Fahnenstiel *et al.*, 1992). It is possible that the lower salinity and higher nutrient concentrations observed in the plume by Lohrenz *et al.* (1992) may have contributed to diatoms being more important in the material collected in the plume sediment traps than for those deployed in the shelf region.

Another factor that can help to explain the observed differences in the proportion of the POM produced in the photic zone that is exported to the sediments is zooplankton grazing activity. One would expect that grazing by macrozooplankton would be dominant in a coastal environment such as that examined here (Ortner *et al.*, 1989). Dilution experiments that can be used to examine the grazing activity of microzooplankton (Landry and Hassett, 1982) were employed on both cruises (Dagg and Ortner, 1992; Fahnenstiel *et al.*, 1992). Their results suggest that microzooplankton grazing, which resulted in more tightly coupled production and regeneration of POM, was more intense during July/August 1990 than in March 1991. Our POM export results support this suggestion in that the fraction of IPP exported to the sediments is much lower when intense microzooplankton grazing was observed. The results of Benner *et al.* (1992) also support the idea that regeneration of organic matter was more important during July/August 1990 than in March 1991. Their bacterial production studies indicate that regeneration rates were an order of magnitude greater in the summer than in the following winter. Conversely, when macrozooplankton grazing activity was more intense (e.g. March 1991), rates of bacterial regeneration were much lower (Benner *et al.*, 1992; Dagg and Ortner, 1992). Thus, it seems likely that decreased regeneration by bacteria and lower rates of microzooplankton

grazing allowed for a larger portion of the IPP to be exported from the photic zone, as is seen in our sediment trap results.

### Conclusions

Our data from the NECOP program studies in the Mississippi River plume and the inner Gulf of Mexico region suggest that during July/August 1990, the production and regeneration of POM were tightly coupled giving rise to a low rate export of POM to the sediments. Conversely, during March 1991, production and regeneration were relatively uncoupled, allowing for a greater fraction of the IPP to be exported from the photic zone. Differences in phytoplankton species composition also contributed to the variability in the ratio of POM export to IPP.

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**National Oceanic and Atmospheric Administration  
Coastal Ocean Program Office**

**Nutrient Enhanced Coastal Ocean Productivity**

**Proceedings of Workshop  
Louisiana Universities Marine Consortium October 1991**

**TAMU-SG-92-109  
June 1992**



Publication of this document supported in part by the National Oceanic and Atmospheric Administration Nutrient Enhanced Coastal Ocean Productivity Program and by Institutional Grant NA16 RG0457-01 to Texas A&M University Sea Grant College Program by the National Sea Grant Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.



## *Nutrient Enhanced Coastal Ocean Productivity Program*

The NECOP Program is part of NOAA's Coastal Ocean Program and is conducted through the NOAA Office of Oceanic and Atmospheric Research through

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TAMU-SG-92-108  
500 June 1992  
NA16RG0457-01  
A/I-1